The Hato Puerco Formation of Cretaceous age, the oldest unit in the quadrangle, is best exposed along the road to Carmelita in the southeast part of the quadrangle. The formation is characterized by an abundance of reddish-brown oxidized lava fragments. The Cambalache Formation, which conformably overlies the Hato Puerco, is characterized by an abundance of long-tube pumice, occurring as "wispy plates and lenses whose axes are oriented more or less parallel to bedding" (Fiske, 1969, p. 3).

Along a dirt road just south of Route 968 and about 300 m east of Cerro El Faro, both formations and their contact are well exposed. Here, the Hato Puerco consists of spheroidally weathered, brown thickbedded lapilli tuff and volcanic breccia containing sparse quantities of long-tube pumice and a large proportion (about 40 percent) of reddishbrown oxidized lava fragments. Six meters of interbedded thinly laminated calcareous siltstone and fine- to coarse-grained tuffaceous volcanic sandstone overlies the Hato Puerco. These beds are assigned to the base of the Cambalache because long-tube pumice is common, although reddish-brown lava grains are conspicuous in the sandstone beds. Overlying these thin-bedded rocks are massive spheroidally weathering lapilli tuff and tuff breccia characteristic of the Camba-

The Cambalache is best exposed in new (1970) roadcuts on the south side of Cerro El Faro where the formation is only 100-120 m thick and is overlain by and is essentially concordant with the Cerro Bravo Andesite. Probably the Cerro Bravo intruded the middle part of the Cambalache, but this relation could not be established with certainty, as the Cambalache is not exposed above the Cerro Bravo. The full thickness of the Cambalache, possibly as much as 400 m, is

poorly exposed along Route 3 between Río Grande and La Dolores; here the Toma de Agua Vitrophyre Member crops out at the top of The Canóvanas Formation conformably overlies the Toma de Agua Vitrophyre Member at La Dolores. The Canóvanas in general is poorly exposed in the Río Grande quadrangle, but just south of Route 3, near Escuela Luis Calderón, siltstone of the upper Canóvanas is exposed in contact with the overlying Martín González Lava. Pillow lava of the Martín González is well exposed in roadcuts on Route 3. Strata correlated with the Frailes Formation (Kaye, 1959a), which overlies the Martín González Lava, are exposed only in the one outcrop in the Que-

brada Cambalache south of Route 3. The only strata of middle Tertiary age exposed in the map area are assigned to the Aymamón Limestone (Miocene) and underlie small areas of low cavernous haystack hills at the west edge of the quad-

Fossils from the Hato Puerco Formation collected by V. M. Seiders and determined by E. A. Pessagno, Jr., to be of late Cenomanian Age, were obtained from one locality in the Río Grande quadrangle (V. M. Seiders, written commun., 1966). This is the easternmost late Cenomanian determination in Puerto Rico and confirms the age of the upper Hato Puerco in its eastern outcrop area.

INTRUSIVE ROCKS

The Cerro Bravo Andesite, an intrusive sheet, is here named for Cerro Bravo, a hill about 95 m high in the eastern part of the quadrangle. The type area is the range of hills that extends from Cerro Bravo to Cerro El Faro. It is recognized in the Río Grande and El Yunque quadrangles only northeast of a line trending northwest through the town of Río Grande. This line is interpreted as a fault on the Río Grande quadrangle but is interpreted as an intrusive contact on the El Yunque quadrangle (Seiders, 1971b). Two small hillocks of the Cerro Bravo protruding from surrounding surficial deposits northwest of the town of Río Grande are also presumed to lie northeast of a buried extension of this fault. The Cerro Bravo is concluded to be an intrusive sheet rising in the

stratigraphic section northward. In its southernmost exposures, in the El Yunque quadrangle, the intrusive cuts strata of the Hato Puerco Formation at a high angle (Seiders, 1971b); southwest of Quebrada Suspiro it transects rocks of the Hato Puerco and Cambalache Formations; and northeast of Quebrada Suspiro it is essentially a concordant sill within the Cambalache Formation. In the southwestern part of the quadrangle, the Cerro Bravo is not

present in the entire section from the upper Hato Puerco to the lower part of the Frailes Formation. Further east, however, in the southeastern Carolina and northeastern Gurabo quadrangles, rocks identical to those in the Cerro Bravo occur in an igneous sheet within the Frailes Formation (Seiders, 1971a). Seiders concluded that this eastern igneous sheet is much like the

Cerro Bravo but separate and appreciably higher in the section. He did not specify a particular time of emplacement of these sheets, but classified them with diabasic porphyry dikes exposed in the Río Grande quadrangle and adjacent areas to which he assigned a Cretaceous or Tertiary age. There is evidence, however, for a comagnatic relation between the Cerro Bravo Andesite, the igneous sheet in the Frailes, and the Martín González Lava of Cretaceous age, and for a younger, Tertiary age for the diabasic dikes (M. H. Pease, Jr., unpub. data).

MARINE DATA

The distribution of shallow-water coralline growth was interpreted from aerial photographs. Included are back-reef sand and marl zones, some of which support extensive aquatic plant growth. Shallowwater areas that are not included in the limits shown are underlain

chiefly by sand. The configuration of the bottom is little known. Submarine contours are taken from the only bathymetric chart available (U.S. Coast and Geodetic Survey Chart 904, 1957), but the notations on the chart of the type of bottom are generally too widely spaced and too simply stated for the present purpose, so these were not placed on the map. The bottom topography, however, reflects the geology of at least a small part of the marine zone. A marine terrace slopes gently seaward from the 10 m to the 15 m isobath. At the north edge of this terrace on the east side of the map is an east-trending submerged hill, and smaller hills with relief less than the contour interval may be present at the edge of the terrace to the west in the quadrangle area, as is suggested by the depth values on U.S. Coast and Geodetic Survey Chart 904. This chart shows a linear relation in the submarine topography between this hill and La Cordillera, about 14 km to the east, and there is a similar relation to Punta Vacía Talega, a similar distance to the west. La Cordillera is a series of low islands composed of sandstone of eolian origin (eolianite) (Kaye, 1959b, p. 96-101, 128) and Punta Vacía Talega is a point of land underlain by eolianite (Kaye, 1959b, p. 79-83, 127-128, pl. 11). It therefore is almost a certainty that the submerged hill is composed of eolianite, and eolianite also may underlie much of the seaward edge of the terrace. The sparse bottom notations on Chart 904 support this interpretation, for along the line in question and nearby, the bottom is characterized as rocky ("rky") or

hard ("hrd"). Other features of the bottom topography are marine terraces, submarine canyons, and the moderately steep slope from about 70 m to perhaps 150 m in depth. The minus 10-15 m terrace is well defined, and another terrace at minus 35-40 m also is indicated. These approximate the 5-fathom and 22-fathom marine terraces inferred by Kaye (1959b, p. 131-133) from Chart 904 and other charts. The submarine canyon opposite the mouth of the Río Espiritu Santo is moderately well developed, and another canyon is indicated opposite Ensenada Comezón. Both may be results of subaerial erosion at lower stands of the sea. The presence of Aymamón Limestone on the west side of the map and the general slope of the foothills underlain by premiddle Tertiary rocks (about 30 m per km to the north) suggest that middle Tertiary limestone may crop out along the minus 70-150 m marine escarpment and in the walls of the submarine canyons. Guillou and Glass (1957, p. 279) divided the shoreline of the Río Grande quadrangle into two classes on the basis of beach-sand characteristics. The beach east of Punta Uvero is predominantly carbonate, but contains appreciable terrigenous sand near the mouths of rivers. West of Punta Uvero the sand is chiefly quartz; sand-sized shell fragments and magnetite are subordinate constituents. Their report includes a semiquantitative analysis of sand from near the mouth of the Río Mameyes (Guillou and Glass, 1957, p. 296, loc. 1A). This analysis revealed no significant minor-element variations with respect to other Puerto Rican sands.

The origin of lunate beaches, such as the beach, at the mouth of the Río Espíritu Santo, was discussed by Kaye (1959b, p. 62-66). Figures 7, 15, and 51 of Kaye's report illustrate features of the coastline of the Río Grande quadrangle.

ENGINEERING GEOLOGY

luvial and swamp areas.

Highway aggregate.—Hard rock suitable for crushing for base and surface courses for highway construction is readily available in the Río Grande quadrangle from the Cerro Bravo Andesite, the small andesite and diabasic intrusive bodies, from some of the tuff breccias and tuffs in the Hato Puerco and Cambalache Formations, and from thicker portions of the Martín González and the Toma de Agua Vitrophyre Mem-

Riprap.—The Cerro Bravo Andesite is the chief source of rocks large enough for use as riprap. General highway and land fill.—Moderately weathered to fresh tuffaceous rocks, lavas, intrusive rocks, Aymamón Limestone, and terrace deposits are all suitable for filling in and raising the levels of low al-

Cerro Bravo Andesite are structurally suitable for use as coarse aggregate. However, prior to such use these materials should be tested for deleterious reactive constituents, the presence of which may cause failure of high-alkali Portland cement. The same restriction holds true for gravels from terraces and alluvium. The alluvial sands when washed and screened are very suitable as fine aggregate. Beach sands are plentiful and the interior beach sands are perhaps most suitable, because they are lower in structurally weak calcite than the sands nearer the shore. However, interior beach sands locally have an appreciable organic content which may prove deleterious in concrete. Slope stability.—Most natural slopes in the Río Grande quadrangle are gentle and may be considered essentially stable. However, in the southeastern part of the quadrangle slopes of 20 percent or more on the Cerro Bravo Andesite and of 30 percent or more on the underlying Cambalache Formation are mantled by sporadic small earth-and-rockflow deposits probably mostly less than 2 m thick, demonstrating naturally unstable conditions. These deposits are composed chiefly of residual boulders and cobbles and clay resulting from weathering of the intrusive sheet. Coalescence of a number of earth-and-rock flows formed the large landslide deposit 400 m northwest of Cerro Bravo. The other landslide deposits are too small and thin to show effectively at the scale of the map. Artificially made slopes in and near the outcrop area of the Cerro Bravo Andesite may fail owing to reactivation of the earth-and-rock flows described.

Artificial cuts in fresh to moderately weathered volcanic rock, in the Cerro Bravo Andesite, and in the Aymamón Limestone commonly will stand well on 3:1 (vertical:horizontal) slopes, except where bedding, shear, or joint planes dip outward from the face of a cut. Where such conditions exist, rock slides and rock falls may occur unless flatter artificial slopes are made. Cuts in these rocks deeper than 10 m should be benched to avoid hazardous rock falls. Alluvium, terrace deposits, and deeply weathered rocks commonly

display a deceptive stability in almost vertical cuts. However, ultimate failure of such steep slopes in these materials is predictable; cut slopes 1:1 or flatter are recommended Foundation strength.—All the volcanic and intrusive bedrock in the quadrangle will provide adequate foundations for all classes of construction except where the presence of landslide deposits warns of unstable conditions. The Aymamón Limestone in general also offers foundation strength, but it should be tested for caverns before heavy construction is attempted.

The thin terrace deposits and alluvium in the upper reaches of streams near the south edge of the quadrangle probably have reasonably high foundation strength, but in most alluvial areas and beneath the beach deposits buried clay lenses and swamp deposits may reduce foundation strength. Swamp deposits, of course, provide very poor

Excavations.—Excavation of all surficial deposits is possible without explosives, and some weathered bedrock may also be ripped to a depth of several meters by machinery alone. Most bedrock, however, will require blasting for moderate to deep excavations, and large residual boulders also may require use of explosives.

ECONOMIC GEOLOGY

Gold.—The Río Espíritu Santo drains areas to the south where goldbearing veins have been reported and where traces of placer gold have been found (D. H. McIntyre, oral commun., 1969). Dredging for gold in the lower flood plain of this river reportedly was attempted in the fourth decade of this century, but the results of this attempt are known only insofar as the undertaking failed. Whether any significant quantities of gold were encountered at all is not known. A method for prospecting the Río Espíritu Santo flood plain for gold is suggested by the heavy character common to gold and the magnetic iron-oxide mineral, magnetite. Ground low-level airborne magnetometer surveys might locate small magnetic anomalies, areas where gold may have been deposited in association with appreciable quantities of magnetite. Copper.—Chalcopyrite is a minor constituent in a few bedrock localities, and gives no promise of economically exploitable copper deposits

Peat.—Peaty muck and peat are common in the coastal plain in the Río Grande quadrangle. They offer a source of concentrated organic material for use as soil conditioner. Peat is also a fuel when dried, but other Puerto Rican peat deposits have high ash contents which probably preclude use of these deposits as a source of fuel (U.S. Bureau of Mines, written commun., 1963). No tests of peat from the Río Grande quadrangle have been made, but there is no reason to suggest that they are significantly different from those that have been tested. Oil and gas.—The prospects for oil and gas in the Río Grande quadrangle are remote. Most of the rocks exposed in the quadrangle are impermeable and fractured by faults and joints; they show little promise as potential source or reservoir rock. The middle Tertiary limestone sequence, which presents at least some promise for oil and gas discovery (Zapp and others, 1948; Briggs, 1969, p. 36), is represented

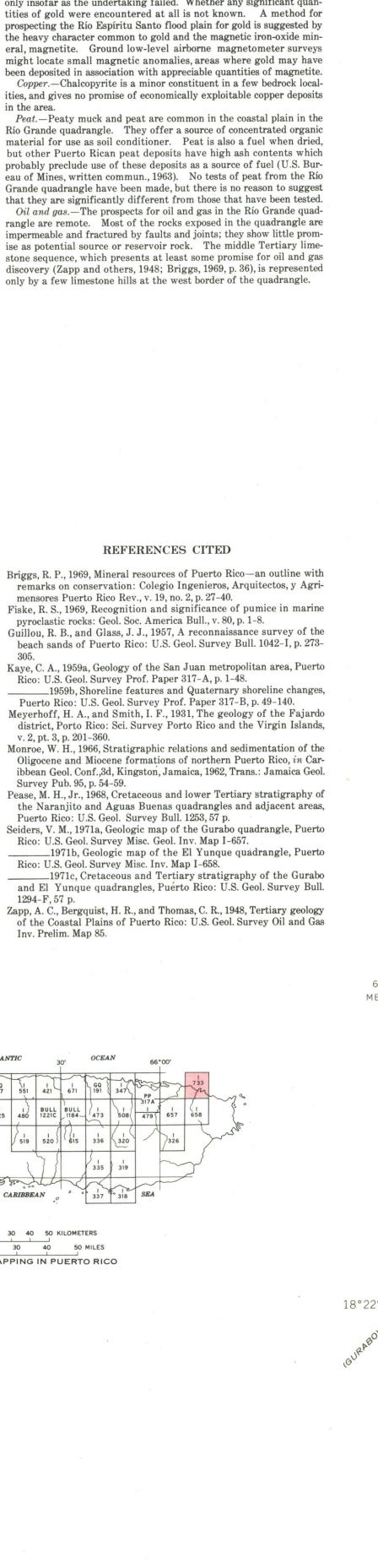
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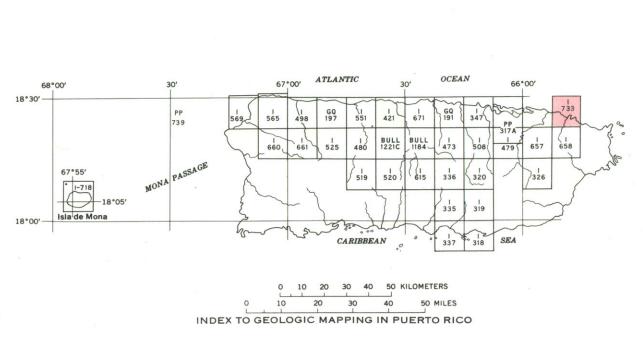
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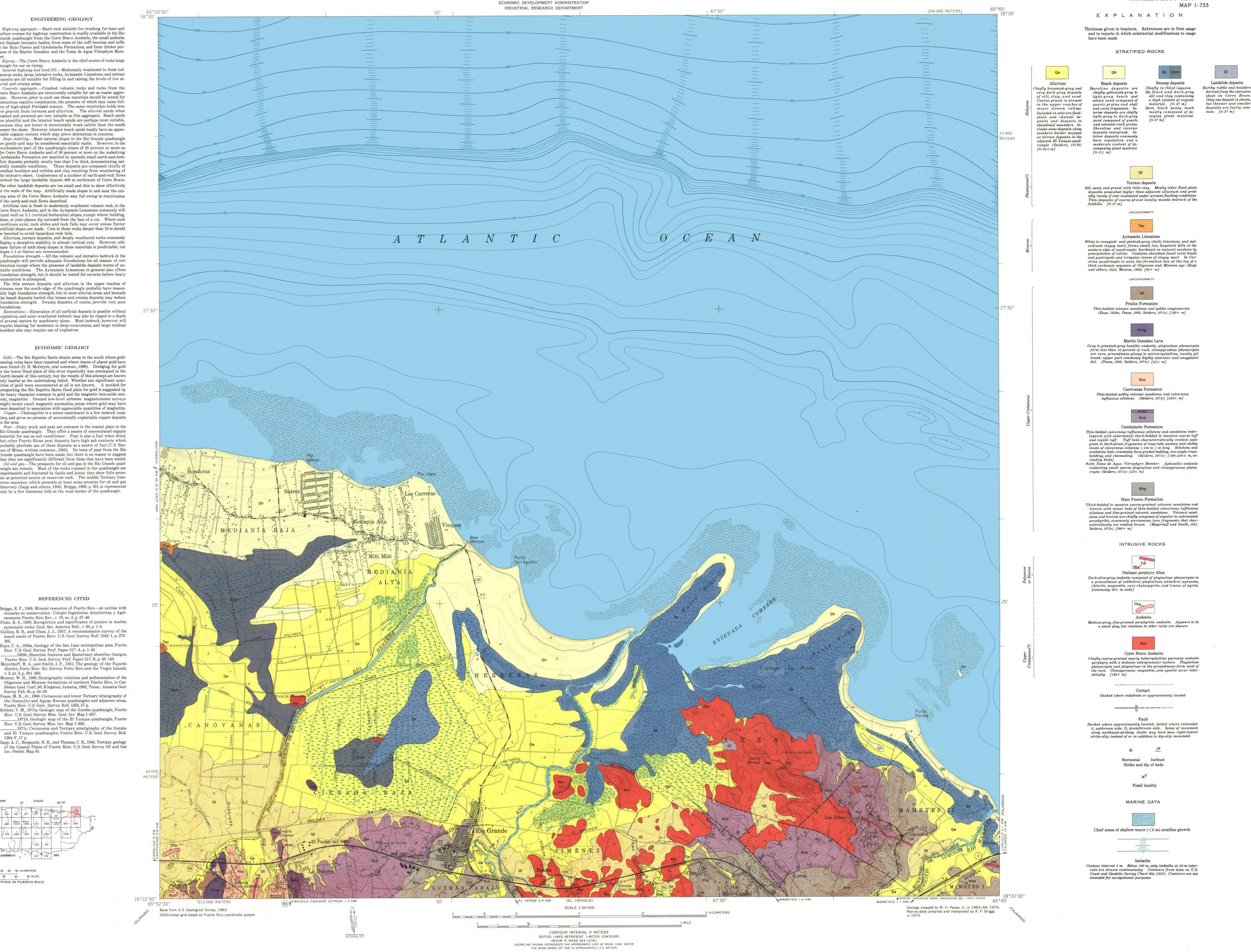
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MISCELLANEOUS GEOLOGIC INVESTIGATIONS